Comparative analysis

Impact scenarios digitalisation and automation on the energy sector

Polish Digital Resilience Agenda 2040 - a model of strategic preparation for the antinomies of digitalisation

Introduction – the context of energy transformation

The energy system is undergoing a fundamental change - from a centralized to a distributed model based on renewable energy. Management complexity increases exponentially, requiring operators to make millions of decisions in milliseconds to hours.

Decentralization

Replacing central units with millions of renewable energy sources.

Complexity

An increase in the number of variables and decisions in real time.

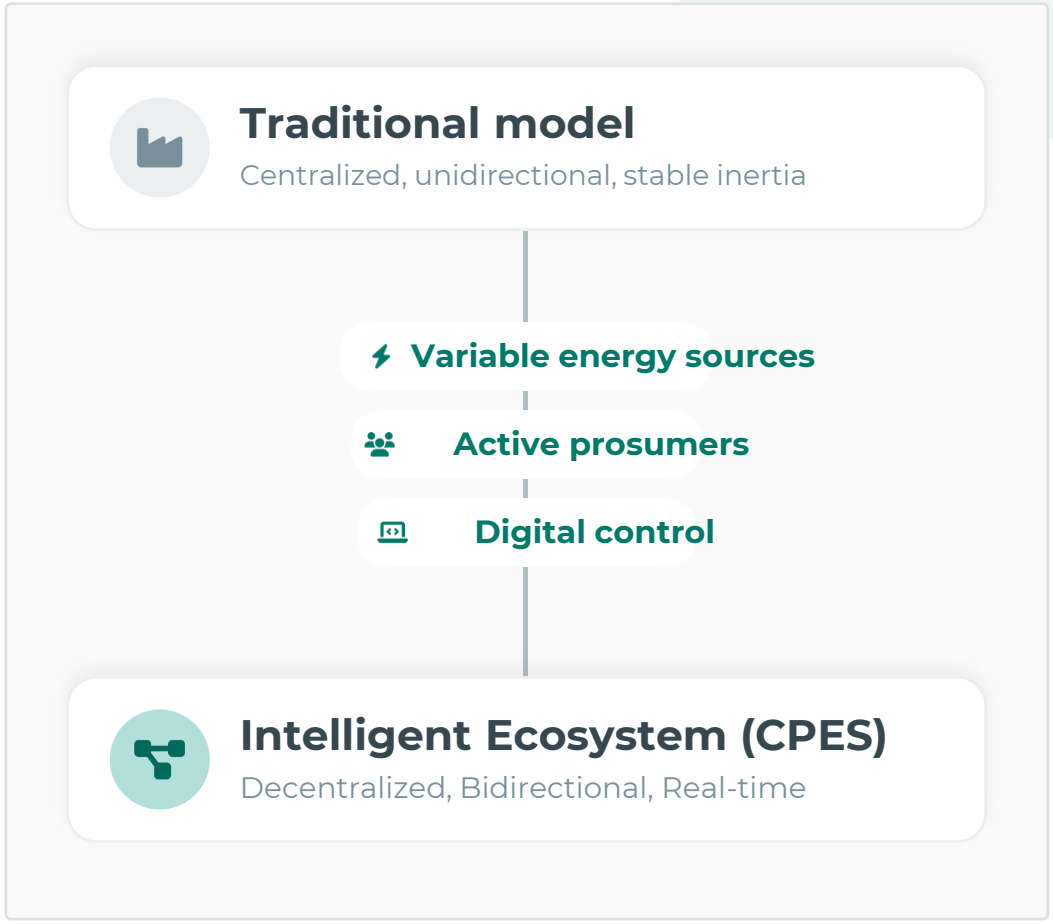
CPES

Cyber-physical systems as a new network architecture.

IT/OT integration

Combination of information and operational technologies.

"Digitalization is not an option, but a critical condition for the security, flexibility and competitiveness of the sector."



Common elements – fundamental technological assumptions

Strategic foundations

Digitalisation as a necessary condition

Automation and digitalisation are absolutely required to manage a complex, decentralized energy system with a high share of renewables.

7 strategic dimensions

Each of the four scenarios operates on the same set of seven transformation pillars, creating a coherent analytical framework regardless of the direction of development.

Operational architecture

Cyber Physical Systems (CPES)

Moving away from hierarchical structures towards adaptive ecosystems connecting the physical and digital worlds.

IT/OT integration

The key combination of IT (data) and operational (control) technologies, enabling full network visibility.

Real-time management

The need to make millions of autonomous decisions on scales ranging from milliseconds to hours to balance the system.

Common elements – key technologies

IoT and sensors

The foundation for collecting operational data in real time from millions of measurement points in the network.

Data acquisition

Artificial intelligence

Advanced algorithms for network optimization, consumption/production prediction and decision automation.

Optimization

Blockchain

Enabling secure P2P energy trading, tokenization of energy assets and transaction transparency.

Transactions

Digital twins

Virtual replicas of physical infrastructure for scenario simulation, optimization and staff training.

Simulation

Edge computing

Edge computing minimizing latency, crucial for fast response of protection automation.

Infrastructure

Cybersecurity

System-wide protection of critical infrastructure against digital threats in a connected IT/OT world.

Security

Common elements – transformation challenges

5-20 thousand

Missing Specialists

Competence deficit

Critical lack of staff combining knowledge in the field of energy and IT necessary to carry out the transformation.

70-80%

Obsolete Systems

SCADA legacy

Most operators still rely on systems from the 1990s that are not adapted to today's threats and requirements.

Silos

No Standards

Technological fragmentation

Low interoperability between systems from different vendors blocks data flow and automation.

PLN 1.2 trillion

Until 2040

Transformation costs

Huge investment outlays (PLN 800-1,200 billion) required for network modernization and new generation capacity.

Positive Scenario

Scenario 1: Resource and potential window

Synergy of technology and natural resources

Distinctive characteristics

Geothermal energy as a foundation

Unique use of Polish geothermal potential to cover approximately 70% of the demand for system heat.

Synergistic reinforcement

The seven pillars of transformation support each other, creating positive feedback for the entire system.

Tokenization and Blockchain

Democratization of investments through equity crowdfunding (asset tokenization) and a transparent P2P market.

Industry 4.0

On-demand production integrated with the energy system as an active, flexible energy consumer.

Key Mechanism & Regulations

Success Mechanism

"Automation is conditio sine qua non - national potentials, intelligent systems and new production paradigms co-create the ecosystem."

⚖Regulatory philosophy

The paradox of liberalization: the combination of traditional deregulation with new algorithmic management protocols.

Smart contracts: automatic contracts replace costly administrative structures.

Positive scenario

Scenario 2: Digital foundation for development

Digital infrastructure priority (IT-first)

Distinctive characteristics

IT-first paradigm

The digital infrastructure becomes the base layer of the system, and the physical infrastructure acts as the application layer.

Three-pillar mix

Stable division: Nuclear energy and CCUS (30-35%), renewable energy (45-50%) and flexibility (15-20%).

Digital agility

Poland is building a competitive advantage as a regional center (hub) of energy technologies in Central Europe.

Regulatory minimalism

The state only defines interoperability standards, and the market decides on the selection of specific technologies.

Key mechanism & regulations

Success Mechanism

"By 2040, digital infrastructure will become the base layer - enabling bidirectional flows and balancing of hundreds of thousands of renewable energy sources."

Regulatory philosophy

Selective deregulation: Rollback of technology mandates and central planning.

Strengthening the framework: emphasis on interoperability standards and protection of data rights.

Conditionally neutral scenario

Scenario 3: "Short Quilt"

Digitalisation as a necessary but not sufficient condition

Distinctive characteristics

The instability trap

There is a risk that pressure on digitalisation without solid foundations will worsen the situation instead of improving it.

"IT implementation desert"

The main barrier to development: many years of neglect, fragmentation of systems and lack of interoperability.

Three-phase roadmap

Plan 2025-2040: 1. Emergency exit, 2. Building foundations, 3. Scaling solutions.

Maturity index

Key strategic goal: raising the digital maturity index from the current 2.1/5 to 4.5/5.

Risk mechanism & strategy

Vicious circle mechanism

"Transformation pressure → chaotic digitalisation → complexity → incidents → less funds for modernization → back to square one."

Recovery strategy

"Emergency exit" priority: PLN 20 billion (2025-2028) to cover technological debt.

Foundations before acceleration: First stabilization and standards, then innovations.

Negative scenario

Scenario 4: Systemic instability

Degenerative spiral and digital fragility

Risk characterization

Degenerative spiral

The seven elements of the system create self-reinforcing loops of destabilization rather than synergy.

Digital fragility

Automation introduced without foundations WORSES the system's resilience instead of strengthening it.

Technical debt

The accumulation of suboptimal solutions leads to an exponential increase in maintenance costs.

Race to the bottom

Cost pressure and competition lead to lower technological and safety standards.

Mechanism of failure & consequences

The mechanism of failure

"Automation becomes a catalyst for destabilization when there is a lack of foundations: mature IT architecture, competences and capital."

⚠Consequences and risks

Cascading failures: +35-45% risk of power outages (blackouts).

Balancing costs: 3x higher than in the optimal scenario.

Competence gap: Deficit of 15-20 thousand. specialists.

Crisis: Risk of "California Crisis 2.0".

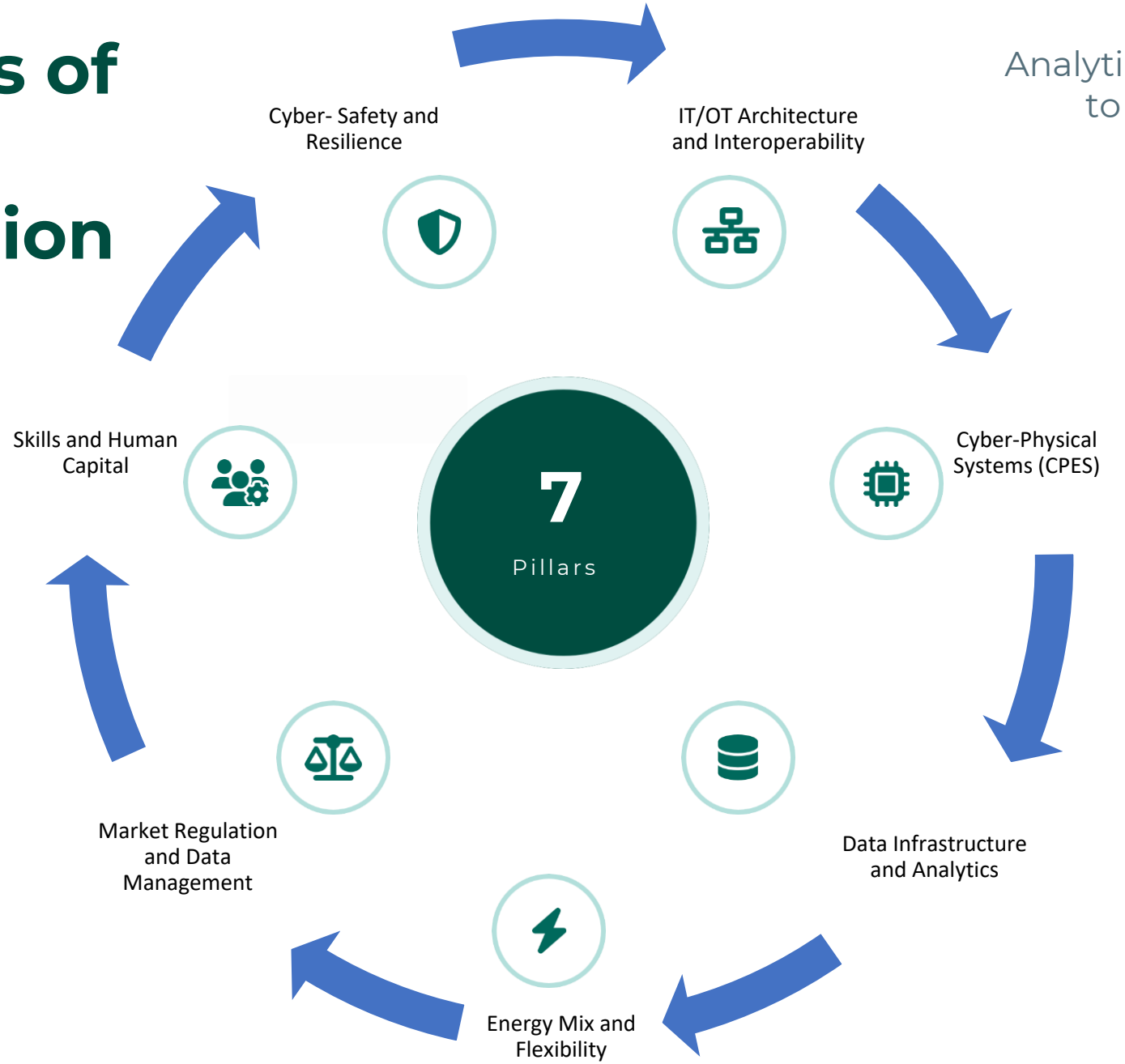
Scenario comparison matrix

A summary of 4 directions of development based on 10 key strategic dimensions

	Scenario 1 Synergistic (Resource Window)	Scenario 2 IT-first (Digital foundation)	Scenario 3 Conditional (Short Quilt)	Scenario 4 Catastrophic (Instability)
The tone of the script	**Optimistic**	**Optimistic**	**Warning**	**Pessimistic**
The role of digitalisation	Synergy enhancer	Fundamental layer	A necessary condition	A source of risk and fragility
Geothermal	Central pillar (70% heat)	Element of the energy mix	Marginally mentioned	Unaddressed
Regulatory model	Algorithmic protocols	Selective minimalism	Necessary standards	Deregulation chaos
Blockchain	Key (tokenization)	Valid (P2P trading)	Replaced (Neutral)	Retarded
Maturity (0-5)	5.0 Reached full	4.8 Reached high	4.5 Goal (start from 2.1)	2.1 Stagnation
IT investments	Distributed in 7 pillars	Embedded in transformation	PLN 20 billion (2025-28)	Chronic deficit
Competencies	Knowledge Diffusion (Solved)	Technology transfer	Deficit 5-7 thousand	Deficit 15-20 thousand + drainage
Cybersecurity	Autonomous AI systems	Competence centers	3 SOC centers	Systemic vulnerability
Result by 2040	Energy subjectivity.	CEE technology hub	Conditional stability	Digital fragility

Seven pillars of strategic transformation

Analytical framework common to all energy development scenarios



Key conclusions and strategic recommendations

"IT-first" foundation

Adopt a paradigm where digital infrastructure is a base layer, not an add-on. Key: coherent architecture and data governance.

Liquidation of the "IT Desert"

PLN 20 billion

An urgent investment program for 2025-2028 aimed at modernizing, consolidating and standardizing outdated SCADA systems.

IT/OT and CPES integration

Accelerating the connection of information and operational technologies and the implementation of cyber-physical systems with real-time automation.

Cybersecurity

3 SOC Centers

Construction of at least 3 sector Security Operations Centers and implementation of autonomous detection systems based on AI.

Competence development

5-20 thousand Spec.

Massive training programs and technology transfer to fill the staffing gap of specialists combining IT and energy knowledge.

Geothermal and Industry 4.0

Use of geothermal potential in heating and integration of smart factories as flexible energy consumers.

Selective regulations

Implementation of interoperability standards and clear data rights while deregulating the selection of specific technologies.

Strategic goal

Transformation from a hierarchical model into a flexible, cyberphysical energy ecosystem, ensuring the security and competitiveness of the Polish economy by 2040.

Summary and roadmap to 2040

Three phases of the digital transformation of the Polish energy sector

2025-2028

Emergency exit from the IT desert

- Migration from legacy SCADA systems to modern platforms
- Implementation of data interoperability standards
- First pilot implementations of CPES and digital twins
- Launch of sector SOC centers

2029-2035

Scale and integration

- Scaling CPES and Edge Computing systems in the distribution network
- Balancing hundreds of thousands of renewable energy sources in real time
- Advanced generation and demand prediction (72-96h)
- Development of P2P trading and asset tokenization

2036-2040

Digital maturity

- Achieving a digital maturity level of 4.5/5+
- Bidirectional energy flows as a market standard
- Poland as a CEE technology hub (in an optimistic scenario)
- Full automation and energy subjectivity

A call to action
The next 6-12 months

- Regulatory decisions (data standards)
- IT modernization investment plan
- Launch of the competence program

Polish Digital Society http://cyfryzacja.org

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